NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Plant Optimization and Systems Engineering

2015 Wind Energy Systems Engineering Workshop

This newsletter edition highlights the third NREL Wind Energy Systems Engineering Workshop took place on the 14th and 15th of January 2015. NREL partnered with DTU wind energy to co-host the biennial event, bringing international perspective to the workshop. This year's theme was exposing interactions in wind energy systems and exploring how different wind energy stakeholders are addressing them in new, integrated, and innovative ways.

Meeting Agenda and Presentations

The full program including abstracts and biographical information on the authors is available online. Links to PDF versions of many of the presentations are available in the summary of the meeting agenda below.

Poster session abstracts and biographical information on the presenters are also available online.

Wednesday–January 14, 2015

Opening Remarks and Keynote

Summary: The Workshop opened with a keynote from Flemming Rasmussen, the head of aeroelastic design section of DTU Wind Energy. Flemming Rasmussen was one of the first people to work in wind energy and wind turbine technology in Denmark and offered his unique outlook on how wind turbine technology has evolved from simple machines to complex wind plant systems. The presentation demonstrated the increasing importance of the physical disciplines in designing robust wind turbines, concluding that the technological development of wind turbines and plants have now developed to a stage where they must be designed as a system.

- **Pierre-Elouan Réthoré**, *DTU Wind Energy*
  Opening Remarks
- **Flemming Rasmussen**, *DTU Wind Energy*
  Keynote Address: Challenges and Perspectives in Future Wind Turbine Technology and the Role of System Engineering

Session I: Cost of Energy for Wind Systems

Summary: The discussion focused on the current and historical cost of wind energy—both land-based and offshore—and how a systems-level approach to wind projects can lead to lowering the cost of wind energy. All panelists agreed that cost reductions in all aspects of wind projects, including turbines, balance of system, annual energy production, are necessary in order to continuously expand the amount of available wind energy produced globally, especially with respect to offshore wind projects.

- **Maureen Hand**, *NREL National Wind Technology Center*
  Cost of Wind Energy in the United States: Trends from 2007 to 2012
- **Bruce Valpy**, *BVG Associates Ltd.*
  Offshore Cost of Energy: Forecasts Based on the European Story so Far
- **Todd Griffith**, *Sandia National Laboratories*
  Cost Reductions in Offshore Wind through Technology Innovation

Session II: Wind Plant Uncertainty—Wind Resource and Financing

Summary: A common theme throughout was the large impact that seemingly small deviations can have on performance. After a high-level overview of the Wind Resource Assessment (WRA) process and the classical uncertainty approach, additional topics covered included the impact of non-linear effects on uncertainty, potential improvements to spatial uncertainty modeling, correlations/covariance of uncertainty, and the uncertainty of uncertainty.

- **Matthew Hendrickson**, *Vaisala Inc.*
  Challenges to the Classical Approach to Uncertainty Calculation
- **Taylor Geer**, *DNV GL–Energy*
  The Impact of Non-Linear Effects on Preconstruction Uncertainty Modeling
- **Michael Brower**, *AWS Truepower*
  Incorporating Spatial Uncertainty Modeling into Wind Plant Development, Design, and Assessment
- **Erik Hale**, *EDF Renewable Energy*
  The Uncertainty of Uncertainty

Lunch Keynote
Summary: Wind plants are complex systems that lend themselves to methodologies from aerospace and other sectors for systems engineering. In 2012, the NWTC began a comprehensive program to assess systems engineering for wind energy applications. This effort led to the development of a research capability and software platform for integrated research, development, and design of wind systems. This talk highlighted the importance of systems engineering to wind energy and provided an overview of some of the recent NREL research in this area, including a comparison of wind plant cost of energy (COE) analysis with models of different levels of fidelity and a detailed set of investigations on the impact of maximum tip speed constraints on wind turbine design and COE.

- Fort Felker, NREL National Wind Technology Center
  Lunch Keynote: A Vision for Systems Engineering Applied to Wind Energy

Session III: Wind Plant Uncertainty—Reliability and Operations
Summary: In order to understand, quantify, and reduce uncertainties found in wind plant reliability and operations uncertainty, the Systems Engineering community provided some inputs so potential solutions can be investigated in the future. Topics covered included SCADA data analysis, a reliability-centered maintenance program, and a utility company's perspective on wind power uncertainty.

- **Carsten Westergaard**, *Sandia National Laboratories*
  Towards a More Robust Understanding of the Uncertainty of Wind Farm Reliability
- **AnneMarie Graves**, *Upwind Solutions*
  Designing for Wind Turbine Reliability
- **Keith Parks**, *Xcel Energy*
  2015 Wind Energy Systems Engineering Workshop

Session IV: Evolution of Wind Turbine Standards and Design Methodologies
Summary: Speakers outlined the progress in three areas: international standards, load simulation, and design evaluation capabilities. All highlighted the tremendous growth in design capability over the years, but also recognized the need to continue to develop and use models as simple as possible for evaluation of complex system innovation opportunities.

- **Sandy Butterfield**, *Boulder Wind Consulting*
  Synergistic Partnership of Standards and Design Process: But What's Next
- **Kenneth Thomson**, *DTU Wind Energy*
  Evolution of Load Simulation Methods in a Systems Engineering Perspective
- **Graeme McCann**, *DNV GL–Energy*

Integrated Wind Plant Simulator for Layout and Control Optimization

Session V: Tools for Integrated System Design
Summary: Three different frameworks for accomplishing wind plant and wind turbine system engineering were presented: OneWind framework, a Modelica-based flexible modelisation tool that can model wind turbines aero-dynamism at various level of fidelities; SINTEF's work towards a linear state-space model of a wind power plant, which included modelling wind turbines response in the frequency domains; and the WISDEM framework, which is composed of a vast collection of wind energy models that can easily be connected in workflow using OpenMDAO and FUSED-Wind standard interfaces to create analysis and optimization tools at various levels of complexity.

- **Urs Wihlfahrt**, *Fraunhofer Institut*
  OneWind Concepts and Products
- **Karl Merz**, *SINTEF Energy Research*
  Towards a Linear State-Space Model of a Wind Power Plant
- **Katherine Dykes**, *NREL National Wind Technology Center*
  Introducing WISDEM™: An Integrated System Model of Wind Turbines and Plants

Session VI: Addressing Uncertainty in the Design Process
Summary: Three perspectives were presented on the uncertainty in turbine simulation, the optimization of wind plants, and their interrelation. Topics included: optimization of Danish offshore wind farms and the FUSED-Wind framework that allows flexibly mixing and matching solvers of different fidelities; how an abstract conception allows for a plethora of advanced mathematical and statistics tools, especially "Active Subspaces," to be applied to loads analysis; and the emerging trend in wind plant optimization in which active controls of individual turbines are used to maximize production of the whole plant.

- **Pierre-Elouan Réthoré**, *DTU Wind Energy*
  TOPFARM: A Wind Farm Optimization Framework
- **Paul Constantine**, *Colorado School of Mines*
  An Active Subspace Study of Offshore Turbine Fatigue with FAST
- **Paul Fleming**, *NREL National Wind Technology Center*
  Combining Wind Plant Control With Systems Engineering

Thursday–January 15, 2015

Opening Remarks and Keynote
Summary: This session provided DOE perspectives on the future of wind energy in the United States as well as the potential role that systems engineering can have in shaping that future. DOE's new Atmosphere to Electrons (A2e) initiative is shifting the DOE research program focus from turbine-centric to plant-centric. This new orientation will require systems level approaches to research, design and development (RD&D) of wind energy systems. Jose Zayas, Wind and Water Power Technologies Office Director, then provided the motivation and context for A2e and systems engineering for wind energy by talking about the DOE Wind Vision initiative, which has looked at the future of wind energy in the United States across a large range of scenarios. The preliminary results of the study showed how, holding other factors constant, innovation plays a key role in accelerating the deployment of wind energy.

- **Sheryas Ananthan**, *U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy (DOE EERE)*
  Opening Remarks
- **Jose Zayas**, *DOE EERE*
  Wind Vision

Session VII: Component Level Design in System Contexts

Summary: There is no single formula to produce the "optimal blade." Different design approaches are applied to determine the shape as well as the structural composition of the blade. The results of optimization analyses can be further investigated via Pareto fronts as a means to quantitatively compare the total system impact of various technology changes on rotor design. Of course, the robustness of these methods is only as good as the input data and parameters. The importance of well-characterized material databases, airfoils aerodynamics, and of a lamination plan that is in line with manufacturing constraints cannot be overstated.

- **Tristan Dhert**, *University of Michigan*
  High-Fidelity Aerodynamic Shape Optimization for Wind Turbines
- **Kristian Dixon**, *Siemens Energy Inc.*
  Multi-Objective Design of the Rotor System
- **Peter Bæk**, *LM Wind Power*
  Rotoropt 2.0: The Power to Deliver

Session VIII: Turbine Level Integrated Design Approaches I
Summary: The first of two sessions on integrated turbine design focused on the trade-offs in performance and cost between the turbine subsystems of the rotor, drivetrain, and tower/support structure. Frederik Zahle of DTU discussed using high-fidelity code to carry out a series of multi-disciplinary optimizations of the aerodynamic and structural design for the rotor of a new 10 MW reference wind turbine. Brian Resor's talk focused on trade-offs between rotor design and the rest of the turbine, including the drivetrain and tower. In a joint study between Sandia and NREL, the effects of maximum tip speed on overall wind plant cost of energy were assessed by focusing on the optimal turbine design for different maximum tip speeds. The study illuminated how design constraints limit the gains achievable from higher tip speeds. Andrew Ning presented a study of a downwind turbine that also found a significant trade-off between the lighter blades and a heavier tower moving from the upwind design case to the downwind design case.

- **Frederik Zahle**, *DTU Wind Energy*
  Aero-Elastic Optimization of a 10 MW Wind Turbine
- **Brian Resor**, *Sandia National Laboratories*
  Effects of Increasing Tip Speed on Wind Turbine Rotor Design Turbine Rotor Design
- **Andrew Ning**, *Brigham Young University*
  Land-based Downwind Wind Turbine Optimization

Session IX: Turbine Level Integrated Design Approaches II
Summary: These presentations focused on the benefits of integrated design for wind turbines. Key innovations discussed included taller towers, integrated tool sets for design of wind turbine towers and drivetrains, and a novel approach to design that includes controls in the optimization loop along with aerodynamic and structural design. In addition, a challenge exists between using integrated modeling and bringing together a variety of different fidelity models together in order to explore how design changes and innovations can impact overall system performance and cost.

- **Patrick Riley**, *GE Global Research*
  Turbine Level Integrated Design Approaches Hub Height Example
- **Jon Campbell**, *Alstom Power Inc.*
  Integrated System Design and Optimization
- **James Allison**, *University of Illinois*
  Integrated Physical and Control System Design for Horizontal Axis Wind Turbines